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13. ABSTRACT *(Maximum 200 words)*

Solar disturbances produce major effects on the corona, the solar wind, the interplanetary medium, and the Earth along with its magnetosphere. We have developed new techniques for studying plasma disturbances in the inner heliosphere by remotely sensing them. These techniques use data from the HELIOS spacecraft zodiacal light photometers, the ISEE-3 spacecraft kilometer radio-wave experiment, and a variety of other spacecraft and ground-based instruments. New in this study is our use of interplanetary scintillation (IPS) data from the Cambridge, England radio telescope. The zodiacal-light photometers on board the two HELIOS spacecraft (data coverage from 1974 to 1986) provide the first good information about the heliospheric masses and shapes of propagating disturbances. Metric and kilometric type II and type III radiation caused by shock waves and fast moving electrons respectively are another way to remotely sense the structures which propagate outward from the Sun. The best kilometric radio-wave sensing of inner heliospheric plasma is available from the ISEE-3 spacecraft, and recently we have been able to use these data to obtain crude images of the Earth's magnetosphere. The investigations into the physics of the disturbances sensed by these techniques and the ability to forecast them are underway.

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Remote Sensing Of Inner Heliospheric Plasmas

I. Introduction

The outermost parts of the solar atmosphere - the corona and solar wind - experience dramatic perturbations related to flares and mass-ejection transients. These disturbances extend to the Earth's magnetosphere and to Earth itself. In the past, observations of the origins of these disturbances in the lower corona have been restricted to coronal emission-line observations and the meter-wave radio band, but since the 1970's we have seen the addition of powerful new observing tools for observation: sensitive coronagraphs, both in space and at terrestrial observatories; X-ray imaging telescopes; low-frequency radio telescopes; space-borne kilometric wave radio receivers; and interplanetary scintillation data.

The primary object of earlier research has been the understanding of the physics and spatial extents of heliospheric structures such as coronal mass ejections, streamers, and the magnetosphere of the Earth. In comparison with spacecraft *in situ* and ground-based data this leads to a better determination of the total mass and energy of these structures, their trapped particle populations and their temporal evolution. In addition, we have addressed the question of how easy these features are to observe and how we can forecast their effects on Earth. This study has resulted primarily from analyzing the data from the zodiacal light photometers on board the HELIOS spacecraft and the kilometric-wave data from the ISEE-3 spacecraft.

We describe our recent results on HELIOS photometer observations of mass ejections, co-rotating density enhancements and other heliospheric features in Section II of this report. In addition, in Section II we describe recent analysis of metric and kilometric radio burst data. These data, which include kilometric observations from ISEE-3, can be used not only to observe heliospheric structures, but also auroral kilometric radiation (AKR) ducted along the magnetotail of Earth. The new research section (Section III) emphasizes the studies we have continued under this contract and concludes with a list of papers and abstracts which have been supported by this contract. Section III also contains a list of the personnel who have been supported by this contract. Section IV states the future goals of the project. Conclusions and an executive summary of the analysis to be performed in the next year is found in Section V.

II. Scientific Background and Recent Results

II.A. The Sun, the Heliosphere and the Magnetosphere of Earth

In association with filament eruptions or large solar flares the Sun emits clouds of ionized gas and entrained magnetic fields (the "coronal mass ejection") and hydrodynamic disturbances (the "shock wave") responsible for some of the magnetic-storm sudden commencements at the Earth. Coronal mass ejections are the most dramatic disturbances of

the heliospheric mass distribution and the ones first detected in the HELIOS photometer data (Richter *et al.*, 1982). The quantitative study of mass ejections essentially began with the Skylab coronagraph (e.g., Rust and Hildner *et al.*, 1980), and has been greatly enhanced by the advent of new coronal instruments. There are data available from the P78-1 and SMM spacecraft, and from mountaintop observatories such as Sacramento Peak and Mauna Loa. In addition, ground-based radio observations provide information on interplanetary scintillations, which are especially useful at high ecliptic latitudes and large solar elongations. In addition to these astronomical observations, there are extensive *in situ* observations from a wide variety of past and present spacecraft. These measurements are generally restricted to the vicinity of the ecliptic plane.

In the lower corona the major ejections observed in $H\alpha$ are termed "eruptive prominences," and are typically associated with a particular kind of flare characterized by two expanding bright ribbons in the chromosphere and a growing system of coronal loops rooted in these ribbons (e.g., Švestka, 1986). The X-ray loops appear to move gradually upward in a steady sequence of diminishing temperature and velocity, and their emission decays with time scales of hours (e.g., Švestka, 1981). These long-duration X-ray events (Kahler, 1977; Sheeley *et al.*, 1983) are known to have a strong association with the ejection of mass into the corona (the coronal transient), the acceleration of interplanetary protons (Kahler *et al.*, 1978), and meter-wave radio phenomena (Webb and Kundu, 1978).

Recent solar X-ray imaging observations (including those from the Japanese Yohkoh spacecraft) have added new data for the phenomenological picture of the origins of coronal mass ejections. Using X-ray imaging and coronagraph data, Harrison *et al.* (1985) argue that rising X-ray arches are involved in the initiation of coronal mass ejections, and in some instances flares, when they occur, are secondary activity at the feet of the arches. We now have evidence that these long-enduring coronal structures may also trap extremely hot thermal sources (e.g., Tsuneta *et al.*, 1984). Cliver *et al.* (1986) argue that such extended hard X-ray bursts are evidence of the acceleration of nonthermal particles in the post-flare loops following mass ejections. X-ray imaging data also revealed large, long-enduring X-ray arches associated with metric radio continua following flares on 21-22 May 1980 (Švestka *et al.*, 1982a), several times on 6 and 7 November 1980 (Švestka *et al.*, 1982b; Švestka, 1984; Farnik *et al.*, 1986) and on 20-22 January 1985 (Hick *et al.*, 1987). These arches coexist with the loop systems, but extend to higher altitudes, survive longer, and coincide in space and time with coronal metric radio phenomena such as type I (short, segmented in time and frequency) and type IV (broad-band continuous) radio emission. Extended bursts of non-thermal hard X-ray emission (Frost and Dennis, 1971; Hudson, 1978) provide another sign that major energy release and particle acceleration may take place in the corona high above and for long periods after the disturbance at the solar surface.

As shown by Webb *et al.* (1980), the ejected coronal mass at the time of a solar flare may be more important energetically than its chromospheric manifestations. Thus it is imperative to study the masses and 3-dimensional structures of the mass ejections in order to understand the flare process. This provides an additional incentive for the study of mass ejection phenomena, over and above our interest in the physical mechanisms involved in the acceleration of mass and particles associated with the mass motions themselves.

The observations from the HELIOS spacecraft photometers (Leinert *et al.*, 1981) provide a link between coronal observations and those obtained *in situ* near Earth. Prior

to these observations, the most frequently used way to obtain information about the interplanetary medium was by radio burst data. Both metric and kilometric radio bursts observed from space have been used as tracers for heliospheric structure and particle propagation.

Metric type I and type IV radiation from the solar corona often associated with solar active regions have been mentioned previously. Metric type III radio bursts (Wild, 1950) are caused by electrons traveling outward through the solar corona at speeds of 0.05 to 0.5 times the speed of light. Often associated with the onset phase of a solar flare (Wild *et al.*, 1954; Loughead *et al.*, 1957; Kane, 1972), these electrons can be traced along open magnetic field lines until they are detected *in situ* (Lin *et al.*, 1973). The actual radio-wave production is thought to be caused by the formation of radio emission at the local plasma frequency from the passing electron stream.

One of the principal locations of interaction between the heliosphere and the Earth is at the magnetospheric boundary. We know from studies by Wilcox (1968) and others that the variations in the heliosphere as determined by measurements of magnetic field, proton density and solar wind speed can be used to determine variations in the magnetic field of the Earth. For lack of any better description of the magnetic field of the Earth, the parameters usually related to heliospheric variations are the AE or Kp indices. The physics behind these variations at Earth lacks a global description of the changes at the magnetospheric boundary simply because the observations of most of the pertinent magnetospheric parameters do not exist.

II.B. The HELIOS Photometer Data

II.B.1. HELIOS Zodiacal Light Photometer Background

The HELIOS spacecraft, the first being launched into heliocentric orbit in 1974, contained sensitive zodiacal-light photometers (Leinert *et al.*, 1981). Each of the two HELIOS spacecraft contained three photometers for the study of the zodiacal-light distribution. These photometers, at 16°, 31°, and 90° ecliptic latitude, swept the celestial sphere to obtain data fixed with respect to the solar direction, with a sample interval of about five hours. The spacecraft were placed in solar orbits that approached to within 0.3 AU of the Sun. The photometers of HELIOS 1 viewed to the south of the ecliptic plane; HELIOS 2 to the north. These photometers were first shown to be sufficiently sensitive to be able to detect variations in density from coronal mass ejections by Richter *et al.* (1982).

An evaluation of these variations provides us with an opportunity to extend the coverage of transient phenomena produced by the Sun in the corona and to reduce some of the ambiguities in the coronal data obtained from the Earth's direction. This stereoscopic capability has been a major objective of the International Solar Polar Mission and of several other proposed deep-space probes, but some of the desired capability exists in these serendipitous HELIOS data. In many mass-ejection events, the mass can be followed right past the HELIOS zenith direction and into the antisolar hemisphere. In the HELIOS data, the contributions of background starlight and zodiacal dust have been calculated and removed from each photometer sector by Leinert and his colleagues, and the complete data set was made available to the National Space Science Data Center (NSSDC). An optical disk containing this data set is now available at UCSD and on request from NSSDC.

The image processing system we have developed has been demonstrated by construction of images of the interplanetary medium in video and motion picture form for specific mass ejection sequences of the data; these data and additional images of specific events have been used to trace the time history of a variety of density enhancements. Recently, these programs have been transferred to the Vax computer at the Geophysics Laboratory, Hanscom AFB, Massachusetts, and the Johns Hopkins Applied Physics Laboratory, Laurel, Maryland. Thus, the capability exists to carry out HELIOS data analysis at any SPAN site. This capability is especially important for co-investigator D. Webb at the Geophysics Laboratory who (though not funded by this program) retains significant interest and collaborative expertise in the analysis of this unique data set, and who now can operate portions of the HELIOS analysis programs at his location.

These data are of interest to the Air Force for several reasons: 1) The understanding of the processes in the heliosphere and its plasma environment are of great importance to the Air Force that operates spacecraft systems and at times maintains a manned presence in space. 2) The ability to observe the outward propagation of structures and particles from the Sun allows researchers to forecast their arrival at Earth. This in turn leads to both a better understanding of how these features interact with the Earth environment and how to determine a more accurate prediction of their effects on Air Force space and communication systems. 3) In recent years the Air Force has proposed placing an orbiting Solar Mass Ejection Imager (SMEI) in space to forecast the arrival at Earth of solar mass ejections, heliospheric shocks, and co-rotating dense regions. By studying the data from the HELIOS spacecraft photometers it is possible to assess the usefulness of the data which an Earth-based imager such as SMEI would provide.

II.B.2. Prior Research with the HELIOS Photometer Data Set

A major achievement of past research at UCSD has been the measurement of interplanetary masses and speeds of coronal mass ejections observed with coronagraphs, interplanetary scintillation measurements and *in situ* spacecraft measurements. The 2-D imaging technique which displays HELIOS data has been developed here. The combination of these data with others to provide stereoscopic views of coronal mass ejections has been used to advantage for each ejection studied (Jackson, 1985a; Jackson *et al.*, 1985; and Jackson and Leinert, 1985; as reviewed in Jackson, 1985b).

The masses obtained from these observations indicate that indeed the material of a mass ejection observed in the lower corona moves coherently outward into the interplanetary medium. In HELIOS photometer data it is possible to sample the brightness of any given ejection over a far greater range of heights than with a coronagraph at one instant. For this reason, individual mass ejections appear to have approximately twice as much mass in the photometer data than in coronagraph observations. By measuring the outward motion of an ejection, the total extent of mass flow past the 16° latitudinal set of photometer sectors can be found and then checked by the 31° set of photometer sectors (e.g., see Jackson, 1985b). The HELIOS data show that not only do coronal mass ejections supply significant mass to the interplanetary medium, but that the mass flow may extend over periods longer than one day.

The shapes of three loop-like mass ejections observed by coronagraphs were measured as they moved past the HELIOS photometers in order to determine their edge-on thicknesses.

Jackson *et al.* (1985) found an angular extent in HELIOS data for each event studied that was nearly the same as in the coronagraph view from the different perspectives which show the loops edge-on. Thus, the implication is that loop-like mass ejections are only loop-like in appearance, and are really large in angular extent observed edge-on.

One coronal mass ejection (that of 21 May 1980) has been studied in detail as to its surface manifestation (McCabe *et al.*, 1986). The perspective view from the HELIOS spacecraft combined with that for SOLWIND allows a far more accurate mass to be determined for this event. It also indicates a highly non-radial motion at the onset of this ejection.

We have followed the mass ejection of 7 May 1979 in a comprehensive analysis from near the solar surface to the furthest extent that can be observed by HELIOS (Jackson *et al.*, 1988). Near-surface observations of this mass ejection show its slowly-moving Hα manifestations, and indicate that this ejection accelerated until it was observed later by HELIOS. Two major prongs of outward-moving material reached a speed of about 500 kms^{-1} as measured from the outward motion observed in HELIOS data. The analysis also includes UCSD interplanetary scintillation (IPS) measurements (Coles and Kaufman, 1978) which show an enhancement of the scintillation level during passage of the excess mass. IPS observations measured a speed of the ejection passage perpendicular to the line-of-sight to 3C48 which compared favorably with the 500 kms^{-1} speed obtained from HELIOS data.

Webb and Jackson (1987) were able to determine an occurrence rate of plasma events with solar cycle from the HELIOS 2 90° photometer. The general characteristics of the *in situ* manifestations of these events have been listed in this earlier study. Although individual events have been shown generally to be mass ejections, both mass ejections and elongated features that rotate with the Sun are observed. Mass ejections are distinguished by their apparent outward motion that is primarily symmetrical to the east of the Sun as well as to the west. Co-rotating structures, on the other hand, can be observed as they move from east to west with time over many days. Using the complete HELIOS 2 90° photometer time series plots which were made available to us courtesy of Ch. Leinert, Webb and Jackson (1990) classified a set of events from 1976 through 1979 for further analysis. Seventy events were temporally located by this means. Using data from all three photometers of HELIOS 2, we were able to determine that a large subset (57 or 80%) of these events were mass ejections rather than other types of heliospheric features.

Persistent elongated features near the solar surface (streamers) that rotate with the Sun and extend outward from it are the most prominent coronal feature observed at the time of an eclipse. The HELIOS observations have been used to measure the extent of these features. The position-angle change with time of these features determines a heliographic latitude and longitude while their curvature with distance from the Sun gives a speed of the outward-moving material. Most of these features appear to map to the heliospheric current sheet. An analysis which gave speeds of $\sim$300 kms^{-1} for over forty of these features to 10% accuracy showed that the speeds of material within these features were constant over latitude and with the solar cycle.

Prior to this contract, a procedure had been developed at UCSD to use month-long stretches of photometer data to display heliospheric brightness in the form of synoptic maps (Hick *et al.*, 1990). These latitude-longitude contour plots give the heliospheric locations of persistent bright features. Present in these data are co-rotating dense regions

and mass ejections throughout the lifetimes of the two HELIOS spacecraft. Interpreted in terms of density, for the first time these data show the latitudinal density structure of the heliosphere beyond the region of primary solar wind acceleration. Using this technique, it is possible when looking to the east of the Sun, to build up a contour map before the co-rotating features arrive at Earth. Thus, the technique demonstrates the possibility of being able to forecast the arrival of these co-rotating features at Earth.

II.B.3. The HELIOS Photometer Data Optical Disk Capability

Until some automatic way of handling the large amounts of HELIOS photometer data was available, we were only able to initiate studies using other observations to select events. In the latter portion of 1989, NSSDC produced a 12-inch optical disk to our specifications which contains all of the information available on the HELIOS 1 and 2 photometer tapes. UCSD now has a copy of that disk and transferred the data on it to a more easily accessed set of two 5-inch optical disks which can be currently read on an optical disk drive available to us. We wrote a set of disk-reading routines which allow easy access to the complete HELIOS photometer data set. Not only is it now possible to use the complete HELIOS data in this manner, but following this example we were able to show the feasibility of having other data sets made available on optical disk by NSSDC.

II.C. Metric and Kilometric Radio-wave Observations

Using radioheliograph techniques, type III burst positions can be shown to be associated with solar active regions (e.g., Kane et al., 1980). Actual type III burst electron production must therefore be caused, or at least largely influenced, by the specific geometry of the active region. Jackson (1986) has proposed a mechanism that relates a specific active region geometry to the production of type III burst electrons. This proposed mechanism is indicated by a position anisotropy discovered in the location of type III bursts surrounding an expanding active region. This mechanism presumes that a current system exists around an active region and that this current indicates the location of the production of type III electrons. The anisotropy was discovered by using two-dimensional images obtained in 1973 and 1977-78 from the Culgoora Radioheliograph (Jackson, 1986), but it is possible to take the analysis much farther.

Type III electrons are observed near the solar surface by the metric radio radiation they produce. When these electrons speed outward into the interplanetary medium, they can be traced in kilometric radio wavelengths. Two studies of immediate interest to the Air Force using this data set are: 1) the placement of the type III burst acceleration within the active region geometry and 2) the observations that the level of type III radio burst activity can increase several hours prior to mass ejections and solar flares (Jackson *et al.*, 1978; Jackson and Sheridan, 1979). We presume that the level of type III burst activity increases prior to coronal changes associated with the emergence of magnetic field from the solar photosphere. These data and the ideas associated with them give a probe of the current systems which surround active regions and a possible mechanism that can be used to forecast the onset of solar flares.

Data obtained from the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Sydney, Australia with the help of R.T. Stewart of Sydney, include the two-dimensional intensity contour plots of over 150 isolated type III bursts and burst groups

that were imaged at Culgoora from June 1978 to November 1979 and from May 1984 through February 1985. The type III burst data during the latter time period from isolated bursts shows that over 35% of the bursts were present at 327 MHz as well as at lower frequencies. In total, over 2000 two-dimensional positions of type III bursts are available for analysis.

II.D. Magnetospheric Imaging using AKR

AKR is naturally-occurring radio radiation thought to arise from plasma processes close to the surface of the Earth. This radiation can be more intense in space near Earth than from man-made sources, is generally of a spiky, short duration, and spreads out from the magnetic poles of the Earth. AKR is generally present in varying amounts throughout the duration of a magnetic substorm. During a magnetic substorm the magnetic field of the Earth (even at its surface) can be shown to undergo large changes in amplitude and direction. According to theory (e.g., Hones, 1979), during a substorm it is possible that the Earth's magnetotail decreases in length by nearly an order of magnitude. The release of a plasmoid from the magnetotail of the Earth directed opposite the Sun into the solar wind is supposed to account for these magnetic variations.

A recent paper by Steinberg *et al.*, (1989) shows the location of the apparent source of AKR observed from ISEE-3 at different frequencies on three different days when the solar wind density had different values. At the time, ISEE-3 was well outside the Earth's magnetosheath. The observations show that, as seen from ISEE-3, the apparent location of the radiation from the spacecraft can be many degrees tailward of the Earth. This implies that the radiation is refracted or ducted along the magnetotail/magnetosheath region until it escapes in the direction of the ISEE-3 spacecraft. The use of this kilometric-wave data is clearly one that will continue to allow information to be derived about the overall structure of the magnetosheath/magnetotail region of Earth when AKR is active.

The Air Force has had a long history of supporting magnetospheric studies. One of the reasons for this has been Air Force communication systems which can be significantly effected by magnetospheric changes. In addition, spacecraft orbiting in geosynchronous orbit at times are outside the magnetosphere of the Earth and at other times are within it. In the past, variations in the magnetosphere have caused not only communication difficulties with Air Force spacecraft, but also excessive charge build-up on these satellites leading to the destruction of instrumentation. Thus, an understanding of the overall magnetospheric structure using remote sensing techniques could be very valuable to the Air Force in a direct way. Beyond this, it may be possible to use the AKR observations to forecast when a substorm, and thus a large change in the magnetosphere of the Earth is about to occur.

III. Research Completed Under This Contract

During the first two years of this contract we have continued research on three aspects of remote sensing of heliospheric plasmas. First, and of primary importance, we have begun new studies with the HELIOS photometer data now available on optical disk. One of the associated benefits of this study and our recent acquisition of interplanetary scintillation (IPS) data daily from Cambridge, England has been its analysis using the very same techniques developed for the HELIOS data analysis. Secondly, we have initiated a variety of studies which deal with the remote sensing observations of solar radio bursts. Finally, in a further study of the same data sets from the ISEE- 3 spacecraft used for solar radio bursts, we have begun to study magnetospheric substorm events by measurement of the propagation of AKR through the magnetosphere of the Earth.

III.A. HELIOS Photometer Remote Sensing

Now that the HELIOS photometer data are available on optical disk, we have begun filling in data for the heliospheric southern hemisphere using observations from HELIOS 1. This is particularly important because the time interval through which HELIOS 1 operated spanned eleven years (one complete solar cycle) from 1974 through 1985. The HELIOS 2 90° photometer was normally not available for this analysis on the zodiacal light data tapes because of a questioned absolute calibration due to the presence of the Large Magellanic Cloud and an uncalibrated wobble of the HELIOS 1 spacecraft over its 6-month orbital period. However, we are interested primarily in the short-term variations in the data temporal sequence. Using data from the optical disk at UCSD and a data set normally not used, but available on the optical disk, we have been able to display the HELIOS 1 90° data for all orbits of the HELIOS 1 spacecraft. From this complete data set from HELIOS 1, we selected all of the significant events ($\sim$300) for further study.

Using this extensive list we published a preliminary study of the solar cycle variation of these data (Webb and Jackson, 1992a; b) showing that the events are far more numerous during solar maximum when more sunspots are present. A further refinement has been the continued analysis of these events by plotting the available lower photometer sequences for them. This allows identification of each event, its detailed comparison with *in situ* observations and imaging. To make this analysis tractable, we have developed several automatic analysis schemes to handle the bulk of data more efficiently. One new data reduction procedure has largely replaced the time-consuming hand-editing that was previously required to make available each section of data. The technique works by filtering the photometer data temporally, after first removing the large component of zodiacal light brightness from the data. To check our procedure, as a control we have also re-analyzed all ($\sim$80) of the significant HELIOS 2 events including those from an earlier (Webb and Jackson, 1990) analysis.

These analyses and the ready availability of the data have lead to a variety of further projects including preliminary papers by Webb and Crooker (1991) and Webb *et al.,* (1992a, b) and Jackson *et al.* (1992). The Crooker study involves the tracing of heliospheric mass ejections in sector boundary regions of the solar wind. Both *in situ* and HELIOS photometer data are used to sort the different structures in these complex regions of space. Crooker *et al.* (1992) continue these analyses and plan additional research. Webb and Jackson (1992b) and Webb *et al.* (1992a,b) continue the 90° event

analysis from the complete data set by determining the solar cycle variation of the CMEs and by comparing the CMEs with the *in situ* plasma and interplanetary magnetic field present at the HELIOS spacecraft.

The co-rotating structures (CRSs) observed by both HELIOS 1 and HELIOS 2 from this set of events (~56 total) also show a general solar cycle variation that is similar in nature to the CME solar cycle variation - more are present at solar maximum. However, the variation with solar cycle of the CRSs is by no means as pronounced as observed for the CMEs. As in the case of the CMEs, the CRSs are compared with the *in situ* manifestations of each event observed in the plasma and interplanetary magnetic field observed by the HELIOS spacecraft. A portion of this study reported in Jackson *et al.* (1992) shows that many of the CRSs are associated with sector boundaries observed in the solar wind.

The Jackson (1991c) presentation at the Solar Wind 7 conference in September in Goslar, Germany was a video of mass ejections observed by the HELIOS photometers. These videos show a sequence of images of five mass ejections as they move outward from the Sun to the farthest distances observed by HELIOS. The Jackson (1991d) review paper presented at the first SOLTIP conference in September in Liblice, Czechoslovakia compares the HELIOS photometer data with IPS data for specific time intervals. Compared are several mass ejections observed by HELIOS with available data from IPS velocity measurements from UCSD (Coles and Kaufman, 1978) and additional data from IPS using the Cambridge, England array (Hewish and Bravo, 1986). The SOLTIP analyses in some instances have been published previously (*i.e.*, Jackson *et al.*, 1988, Hick *et al.*, 1992), but here the information is gathered together. In the final portion of the review, there is an attempt for the first time to reconcile the differences between the Cambridge IPS and the HELIOS masses for a mass ejection observed leaving the Sun on 27 April 1979.

The automatic analysis techniques have allowed the display of photometer data into month-long data sequences in the form of synoptic maps (as in Hick *et al.*, 1990). In the preliminary report (Hick *et al.*, 1992) we have been able to compare these maps with IPS velocity maps (Rickett and Coles, 1991), K-coronameter maps (Fisher and Sime, 1984) and magnetic field maps (Hoeksema *et al.*, 1983). The HELIOS observations clearly show the organized heliographic equator enhancement of density at solar minimum and a depletion of the density over the solar poles. As solar maximum approaches the enhanced density increases in latitude until at the time of maximum the whole of the Sun is surrounded by dense solar wind. This effect has been concluded from circumstantial evidence nearer the solar surface by others, but has never before been as directly observed above the primary region of solar wind acceleration (where the HELIOS photometers are sensitive).

These observations above the acceleration region of the solar wind allow a direct comparison of the solar wind density variations with solar wind speed from IPS velocity data. In particular Hick and Jackson (1992) in a preliminary analysis show that over different heliographic latitudes, momentum flux (mV^2) [and not mass flux (mV) or energy flux (mV^3)] is most likely conserved for different speed solar wind. The implications of this observation are far reaching, for it means that the total energy input by the Sun to the solar wind is constant over latitude and does not depend on the solar magnetic field near the solar surface.

III.B. Metric and Kilometric Solar Radio Burst Observations

In recent studies, Jackson and Leblanc (1989) and Leblanc and Jackson (1989) show that some type III electrons can be traced all the way from the Sun to Earth. In these studies, data from the low-energy electron experiment on ISEE-3 which operated in 1978 and 1979 can then be used to determine the energies and particle distributions of each of these events. Approximately 100 of these events have been associated temporally with solar flares. In a recently published paper (Jackson and Leblanc, 1991) these data have been used to calibrate the beam shape and determine the total number of electrons and energies for these events. We find total energies and electron numbers that average an order of magnitude larger than measurements by others primarily because the beam size implied by this technique is so large.

III.C. Analysis of AKR Magnetospheric Propagation Paths

Prior to the AKR observations described in the last section, there has been almost no way to observe the overall global configuration of the magnetosphere of the Earth. Our preliminary analysis (Jackson and Steinberg, 1990) of the AKR data to date has dealt primarily with the determination of the *average* positional directions of AKR caused by a variety of factors. We continue to develop these techniques which are used to determine magnetospheric propagation paths of AKR to the ISEE-3 spacecraft during 1982-83 when the spacecraft was outside the magnetosheath of the Earth at approximately the distance of the moon or greater. One study centers on the determination of the changes in the directional positions, extents and intensities of the AKR during the times of stable but differing solar wind conditions. Both the solar wind density and velocity affect the propagation path of the AKR. A simple magnetospheric density model is being developed in an attempt to understand the effects on the AKR propagation observed. In addition, J.L. Steinberg of Meudon has developed a ray-tracing program for kilometric radiation propagation through this density model in order to model many of the effects observed in the AKR data. The study of the AKR during times of stable solar wind conditions are continued in conjunction with observations at times of substorm activity where the apparent source position of the AKR is observed to vary by large amounts over time intervals of a few hours or less.

More than fifty AKR events (Jackson, 1991b) have been located in the data where the apparent source of the radiation changes direction by many degrees in the course of several hours. Often, these direction changes begin with a gradually increasing shift in the direction of the apparent source location away from the Sun followed by a rapid return to the original apparent source location. Solar wind parameter changes which could cause the rapid AKR propagation changes are monitored throughout the events and often show no systematic associated density or velocity change. When changes such as magnetic field direction reversals occur in the solar wind which appear to trigger the apparent source location changes, they are timed more with a change of the parameter near Earth than with its change near the ISEE-3 spacecraft. It therefore follows that the propagation path changes for these events are most likely caused by a large-scale rearrangement of the magnetosphere of the Earth.

IV. Future Projects

IV.A. HELIOS Photometer Remote Sensing

We now have a list of approximately 400 events observed by the HELIOS photometers from 1974 through 1985, and we have now determined whether each event is either a mass ejection or a co-rotating. All 160 certain CMEs have had speeds determined for them and a quality of this measurement given for each. We are well on our way in determining the masses for each CME observed by HELIOS 1 and 2. Following a study of Solwind coronagraph CME masses (Jackson and Howard, 1992), there should be enough events present in HELIOS CME sample to determine if the number of events versus mass follow an exponential curve, and to what limits these masses agree with the values derived from coronagraph observations. The CME masses observed by HELIOS are a more direct measure of the masses present in the solar wind since the measurements are obtained beyond the region of primary solar wind (and CME) acceleration. The Jackson and Howard (1992) coronagraph CME mass determination shows that perhaps as much as 23% of the solar wind mass is comprised of CME mass. We wish to compare the HELIOS determined masses with the coronagraph results.

We would like to determine the solar surface origins of mass ejections by imaging individual events and comparing those from 1979 to 1985 with coronal mass ejections observed by SOLWIND and the SMM coronagraphs. In addition we would like to compare the HELIOS mass ejections with other forms of solar activity such as disappearing filaments and solar flares. One comparison study of these data deals with the extent of mass ejections and whether it is possible to determine the magnitude of the southward-directed magnetic field component when a mass ejection arrives at Earth using pre-existing magnetic fields. We will attempt to extrapolate models of pre-existing solar surface magnetic fields to the HELIOS spacecraft location and compare them with HELIOS *in situ* magnetic field observations. We have begun to compare the HELIOS CMEs with other related interplanetary events such as magnetic clouds, bi-directional streaming proton events and shocks.

Important in this study will be collaborations with others (e.g., T. Hoeksema of Stanford University, and J. Gosling of Los Alamos) who have important experience working with these data in the past. The HELIOS *in situ* data also have the ability to show the location of bi-directional streaming electrons which Gosling *et al.* (1987) claim to be a certain *in situ* manifestation of CMEs in the solar wind. If the bi-directional electron fluxes from HELIOS can be made available from the many hundreds of data tapes on which these data currently reside, we can make this comparison. To this end one of us (P. Hick) has completed a tape-reading program that can compress the original HELIOS *in situ* data tapes to optical disk. We expect this comparison to proceed over the final year of this contract. The optical disk data access and display programs to enable these comparisons have been produced over the last year by students at UCSD from a two-week sample of data available from a preliminary version of the optical disks. Thus we are ready for these analyses as these data become completely available.

Also, still to be studied are the solar surface manifestations of co-rotating structures (CRSs) and the available heliospheric observations which can be compared with them. We can do this by comparing the HELIOS synoptic map data with other synoptic maps or more directly, feature by feature. Each of the 56 CRSs in the newest sample from HELIOS 1 and 2 has been modeled as in Jackson (1991a) to determine the solar latitude,

longitude and material speed of each. In addition, each has been modeled to determine if it is decreasing or increasing in density relative to the ambient with height above the Sun. The majority of the features in this new sample decrease in density relative to the ambient with height above the Sun, and thus were probably most dense near the solar surface and could have been observed as coronal streamers (Jackson, 1991a). However, a few of the features increase in density with height above the solar surface. We wish to ascertain the conditions surrounding each class of feature in order to determine what interplanetary characteristics they have in common. The preliminary Jackson et al. (1992) study shows that 40% of these CRSs are associated with sector boundaries *in situ* when projected back to the solar surface show almost the same association.

Through collaboration with NOAA, and more recently by direct access from Cambridge, England, we have been able to obtain the IPS data daily from the IPS array telescope there. With very little effort, we have been able to modify our HELIOS photometer data display programs to produce a daily map of the sky around Earth much as is done at NOAA in their attempt to forecast the arrival of heliospheric disturbances at Earth. We clearly see these heliospheric disturbances, but note as does the group at NOAA that by the time most disturbances are well-observed, they have already reached the Earth. We try to improve the signal to noise present in the data by careful editing or display of the data in the hope that they may become more useful as a disturbance forecast technique (Winfield et al., 1993). Comparisons of these data with other similar data sets are currently underway. This includes data from the Japanese Yohkoh spacecraft soft x-ray images of the Sun.

The Carrington synoptic presentation of data used to compare the HELIOS photometer data with other data sets has been modified to read daily IPS intensities and forecast the co-rotating component of the IPS level. These synoptic maps have been compared with other forms of solar surface and heliospheric *in situ* data from Earth-orbiting IMP spacecraft. Each day we produce a forecast map for co-rotating IPS scintillation levels similar to that shown in Figure 1. From statistical comparison of the co-rotating component of the IPS intensity level shown in the map, we find a slight positive correlation between the forecast level of IPS intensity several days in the future and the proton density at Earth or the interplanetary magnetic field data when that day arrives. An even higher positive correlation to date has been found between the forecast IPS scintillation level and the Earth geomagnetic Ap index. We expect the co-rotating component of the solar wind to become more dominant as solar activity declines, and we expect our ability to forecast changes at Earth to increase with declining solar activity. We continue our attempts to refine this forecast technique in the hope that it will ultimately produce worthwile results.

IV.B. Metric and Kilometric Solar Radio Burst Measurements

We have initiated several studies using the metric type III radio burst data at our disposal. As electrons of a type III burst move outward from the Sun, the interplanetary medium near them emits kilometric radiation. Knowledge of the near-solar-surface locations of these bursts, their origins in time relative to solar flares, and their paths through the heliosphere provide a powerful tool to study these events. In addition, the ability to measure the energies of these electrons *in situ* give further information about the ac-

celeration processes which initiates them. We have begun to incorporate the intensities of kilometric type III bursts and their heliospheric positions into the project of tracing these bursts outward from the Sun. This would both help to calibrate the type III burst radiation and determine the paths of the electrons as well as trace the extent and shape of the magnetic field from Sun to Earth. This study in turn may help determine which acceleration mechanism is responsible for the more energetic (and potentially dangerous) protons.

Kilometric-wave observations of type II radio bursts reportedly measure positions and propagation of heliospheric shocks. These can be shown to be well-correlated with mass ejections observed by coronagraphs (e.g., Cane et al., 1987). A comparison of corresponding data from the two data sets is possible since they overlap in time quite well. We expect to initiate comparison studies between the HELIOS photometer data and the ISEE-3 data to determine if the heliospheric positions which show type II radio bursts are easily observed heliospheric density enhancements, or if they have other distinguishing characteristics that can be traced to the denser regions of the heliosphere.

IV.C. AKR Analysis

Currently in preparation are two papers which detail the findings of the current work. In one paper the AKR propagation in the magnetosphere is documented as it pertains to different stable solar wind *in situ* parameters. In another paper, the analysis of the events observed in the data are detailed. Dr. Jackson is an occasional guest visitor at the Observatory of Paris at Meudon under the sponsorship of J.L. Steinberg, P.I. of the ISEE-3 kilometric instrument. A visit this year at no cost to the Air Force has occurred in April. An additional visit is planned in April 1993.

It is possible to determine the spatial locations of AKR from only half a rotation of the spacecraft in some instances. Throughout the period of substorm activity when AKR is active, the location of the AKR shows the extent of the magnetotail/magnetosheath region of the Earth. We expect to initiate data access from the original ISEE-3 data files. We plan to do this with an eye to the problems specific to the spiky AKR data in the hope that we can obtain more information from the AKR data than has previously been available. From these data we intend to determine the apparent source direction of the AKR at different frequencies, its modeled size and its intensity.

Using these parameters we will construct AKR images and will attempt to determine the gross magnetospheric structure responsible for the displacement of the AKR. In addition, it may be possible to use the spatial location of the AKR to help forecast the onset of substorm activity and its extent. With this new data set and measurements of positional changes in the magnetotail, it may be possible to view magnetospheric changes high above the surface of the Earth and prior to its manifestation near the surface. As the data are being analyzed, we will search the spatial information obtained for clues that this forecast possibility exists in the data.

We expect that data from other spacecraft within the magnetotail/magnetosheath region of the Earth at these times will be able to show the general *in situ* density and magnetic field. These point measurements can be extrapolated using modeling techniques. Combined with the positional information available from apparent sources of AKR at the same time, we may be able to observe a change in the apparent AKR source location

relative to the Earth. Thus, we plan also to locate the additional spacecraft data that can be used to extrapolate information about the magnetosheath/magnetotail region of Earth at these times.

With both sets of data, from spacecraft near the Earth and ISEE-3, we will attempt to map the location of various magnetospheric features. By a combination of modeling and the ray-tracing capability now available at the Observatory of Paris, we expect that we will be able to explain the structure of the magnetotail/magnetosheath region of Earth. Two important physical questions will be asked:

1) To what extent can one deconvolve the magnetotail/magnetosheath structures of the Earth using ISEE-3 data?

2) To what extent could the same structures be determined if one had more sophisticated instruments for observing AKR and other sources of kilometric radiation?

The publications which have benefitted from this grant or form the basis of research from it follow:

Recent Publications

Research Articles

1. Jackson, B. V. and Y. Leblanc, "Type III Electron Beamwidth from Solar Flare Longitudinal Distributions," in *Plasma Phenomena in Solar Physics* M.A. Dubois, D. Gresillon and F. Bely Dubou, eds., L'Edition Du Physique, L'Ecole Polytechnique, 91128 Palaiseau Cedex, France, 209 (1989) (pg. 209-217).

2. Leblanc, Y. and B. Jackson, "Type III Bursts Traced from the Solar Surface to 1AU," in IAU Symposium 142, *Basic Plasma Processes on the Sun*, E.R. Priest and V. Krishan, eds., 509 (1989) (pg. 509-512).

3. Hick, P., B.V. Jackson and R. Schwenn, "Synoptic Maps for the Heliospheric Thomson Scattering Brightness as Observed by the Helios Photometers", *Astron. Astrophys.*, 285 (1990) (pg. 285-1 through 285-9).

4. Jackson, B.V. and J.L. Steinberg, "Broad-Band Images of AKR from ISEE-3", in the proceedings of the Low Frequency Astrophysics from Space Workshop in Crystal City, Virginia January 8 and 9, 1990, in *Lecture Notes in Physics*, **362**, Namir E. Kassim and Kurt W. Weiler eds., 102, (1990) (pg. 102 - 105).

5. Webb, D.F. and B. Jackson, "The Identification and Characteristics of Solar Mass Ejections Observed in the Heliosphere by the Helios-2 Photometers," *J. Geophys. Res.*, **95**, 20641 (1990) (pg. 20,641 - 20,661).

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10. Jackson, B.V. D.F. Webb, R.C. Altrock and R. Gold, "Considerations of a Solar Mass Ejection Imager in Low–Earth Orbit", in *Eruptive Solar Flares - Lecture Notes in Physics*, **399**, the proceedings of IAU Colloquium 133 held in Iguazu, Argentina 2-6 August, 1991, Z. Svestka, B.V. Jackson and M.E. Machado, eds. Springer-Verlag, Heidelberg, (1992) (pg. 322 - 328).

11. Jackson, B.V., "Remote Sensing Observations of Mass Ejections and Shocks in Interplanetary Space", in *Eruptive Solar Flares - Lecture Notes in Physics*, **399**, the proceedings of IAU Colloquium 133 held in Iguazu, Argentina 2-6 August, 1991, Z. Svestka, B.V. Jackson and M.E. Machado, eds. Springer-Verlag, Heidelberg, (1992) (pg. 248 - 257). +

12. Jackson, B.V., "Comparison of Helios Photometer and Interplanetary Scintillation Observations", in Proceedings of the First SOLTIP Symposium held in Liblice, Czechoslovakia 30 September - 5 October, S. Fischer and M. Vandas, eds. Astronomical Institute of the Czechoslovak Academy of Sciences, Prague, (1991) (pg. 153 - 164). +

13. Hick, P.L., Jackson, B.V. and R. Schwenn, "Synoptic Maps of Thomson Scattering Brightness from 1974 - 1985 as Observed by the Helios Photometers", in *Solar Wind Seven*, E. Marsch and R. Schwenn, eds., Pergamon, Oxford, (1992) (pg. 187 - 190). +

14. Webb, D.F. and B.V. Jackson, "Characteristics of CMEs Observed in the Heliosphere Using the Helios Photometer Data", in *Solar Wind Seven*, E. Marsch and R. Schwenn, eds., Pergamon, Oxford, (1992) (pg. 681 - 684). +

15. Jackson, B.V., "Solar Generated Disturbances in the Heliosphere", in *Solar Wind Seven*, E. Marsch and R. Schwenn, eds., Pergamon, Oxford, (1992) (pg. 623 - 634). +

Work In Progress

1. Jackson, B.V. and H.R. Froehling, "Three-Dimensional Reconstruction of Coronal Mass Ejections", in preparation to be submitted to *Astron. Astrophys.*, (15 pages). +

2. Webb, D.F., and B.V. Jackson, "Characteristics of CMEs Observed in the Heliosphere Using Helios Photometer and In-situ Data", to the Solar Terrestrial Predictions Workshop meeting in Ottawa, Canada 18 - 22 May, submitted (1992) (6 pages). +

3. Webb, D.F., D.V. Reames and B.V. Jackson, "Study of the Structure of CMEs Observed in the Heliosphere Using Helios Photometer and Bidirectionally Streaming Proton Data", to the STEP Workshop in Laurel, Maryland 24 - 28 August, submitted (1992) (4 pages).

4. Jackson, B.V., "A model for coronal streamer observations using the SOHO coronagraph instrumentation", submitted to the *Proceedings of the SOHO Workshop on Coronal Streamers, Coronal Loops and Coronal and Solar Wind Composition* in Annapolis, Maryland 25-28 August 1992. (1992) (3 pages). +

5. Jackson, B.V., P. Hick and D.F. Webb, "Co-Rotating structures of the inner heliosphere from studies of Helios photometer and in-situ data", submitted to *Adv. in Space Res.* (1992) (4 pages). +

6. Webb, D.F., B.V. Jackson, P. Hick, R. Schwenn and V. Bothmer and D. Reames, "Comparison of CMEs, magnetic clouds, and bidirectionally streaming particle events in the heliosphere using Helios data", submitted to *Adv. in Space Res.* (1992) (4 pages). +

7. Hick, P., and B. Jackson, "Solar wind mass and momentum flux variations at 0.3 AU", submitted to *Adv. in Space Res.* (1992) (4 pages). +

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1. Hick, P., B.V. Jackson and R. Schwenn, "On Representing the Large-scale Structure of the Inner Heliosphere in Synoptic Maps", SPD/AAS June meeting, 1990, *BAAS*, **22**, 810 (1990).

2. Jackson, B., R. Gold and R. Altrock, "The Solar Mass Ejection Imager", XXVIII COSPAR meeting The Hague, The Netherlands 25 June - 6 July (1990).

3. Hick, P., B.V. Jackson and R. Schwenn, "Synoptic Maps Constructed from Brightness Observations of Thomson Scattering by Heliospheric Electrons", XXVIII COSPAR meeting The Hague, The Netherlands 25 June - 6 July (1990).

4. Gold, R., B.V. Jackson and R. Altrock, "The Solar Mass Ejection Imager", AGU fall meeting, 1990, *EOS*, **71**, 1516, (1990).

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9. Jackson, B.V. "Remote Sensing Observations of Mass Ejections and Shocks in Interplanetary Space", presented at IAU Colloquium 133 on Eruptive Solar Flares held in Iguazu, Argentina 2-6 August (1991).

10. Jackson, B.V., "The Dynamics of Mass Ejections in the Heliosphere Observed Using Helios Photometer Data", presented at Solar Wind 7 held in Goslar, Germany 16-21 September (1991).

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13. Jackson, B.V., "Solar Generated Disturbances in the Heliosphere", presented at Solar Wind 7 held in Goslar, Germany 16-21 September (1991).

14. Webb, D.F. and N.U. Crooker, " Heliospheric Evolution of the Coronal Streamer Belt", presented at Solar Wind 7 held in Goslar, Germany 16-21 September (1991).

15. Jackson, B.V., "Comparison of Helios Photometer and Interplanetary Scintillation Observations", presented at the first SOLTIP Symposium held in Liblice, Czechoslovakia 30 September - 5 October (1991).

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26. A. Buffington and B.V. Jackson, "Solar Mass Ejection Imager: A Precision Photometer for Time-series Measurements of Stars Solar System Objects", to be presented at the AAS January meeting (1993).

UCSD Personnel Supported by this Contract

1. B. Jackson – Associate Research Physicist
2. P. Hick – Assistant Research Physicist
3. T. Davidson – student
4. J. Jones – student
5. J. Lang – student
6. J. Nelson – student
7. S. Rappoport – student
8. K. Winfield – student
9. S. Pettijohn – secretary

V. Conclusions and Executive Summary

Much work has been accomplished from the comparison of HELIOS photometer observations with coronagraph observations and other data. Now these HELIOS data are

available on optical disk, and we have begun to initiate new studies by using the whole data set more effectively. Our data base provides a uniform and sensitive observational foundation for long-term global studies. The wealth of data provides a statistical base to study the effect of each event and its comparison to other known manifestation of the event. One further objective of the study with D. Webb at the Geophysics Lab is to continue and extend our work on mass ejections and co-rotating structures including their comparison with the bi-directional electrons supposed to be the *in situ* manifestations of solar wind CMEs.

The outcome of the Cambridge, England intensity IPS data comparison with other data sets leaves much to be desired as far as its use as a forecast technique is concerned. However, we wish to pursue these comparisons as solar activity declines in the hope that co-rotating features of the solar wind become more dominant, and will allow a more fruitful forecast at times of low solar activity.

We have encorporated the kilometric data and metric type III burst positions into our study of type III electron beam widths. We would like to continue this study to determine the total energies and electron numbers in the solar wind in order to understand how these high energy particles propagate to Earth. In addition, we intend to use the burst positions to trace open field lines surrounding active regions which produce type III bursts.

AKR observed from beyond the magnetosheath of the Earth provides a technique for gathering information about the global shape of the magnetosphere. We intend to find out from the best data currently available, the extent to which this imaging procedure can be used. Not only do we expect to better understand the global density structure of the magnetosphere better, but we may also be able to observe how this structure acts during a magnetic substorm. Future instrumentation and AKR imaging techniques will surely follow if these analyses prove valuable.

These studies are of vital interest to the Air Force. This interest goes beyond a wish to know the detail of how the processes work in order to form a more comprehensive understanding of them. In each case for this research we include in the study the possibility of being able to forecast the arrival of these structures at Earth or their occurrence prior to their manifestations in the near-Earth environment.

In summary, the object of this research is to study the problems associated with heliospheric plasma processes by viewing interplanetary structures and by following energetic electrons from the Sun to 1 AU. Since most of the interaction of the heliosphere with Earth takes place at the outer boundary of the magnetosphere, we would also like to study its extent. Prior to our development of new methods to determine heliospheric structures and trace its magnetic field, studies of these features had to rely on large, incomplete extrapolations from *in situ* spacecraft measurements and near-solar surface observations. This research will greatly enhance the study of these heliospheric structures to the point that it will be possible to tell how they interact quantitatively with the Earth. The quantitative assessments include the basic heliospheric structure parameters which affect Earth such as shape, mass, speed and magnetic field. These parameters are not currently available by any other means. Not only do we wish to study the heliospheric structures that interact with Earth, but we also wish to view one of the primary interaction processes that takes place at Earth (at the magnetospheric interface) by using one of these same remote-sensing techniques.

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Figure Caption

Figure 1. A recent (19 November 1992) synoptic Carrington map for the co-rotating IPS intensity level (G value) relative to the Earth. Heliographic latitude (±90°) and Carrington longitude (0-360° form the vertical and horizontal axes of the plot, respectively, at the distance of the Earth from the Sun (1 A.U.) The IPS intensity levels are shaded; the nominal value for this is 100. The Earth is marked on the upper day-of-year scale, in the Carrington map at the proper heliographic latitude and near the bottom of the figure. The plot at the bottom of the figure indicates the intensity level at the latitude of Earth. The values which have past Earth (to the right of the Earth symbol) and which will co-rotate to Earth (to the left of the Earth symbol) are shown relative to this symbol. On 19 November 1992 the plot indicates that the Earth is soon (within one or two days) to be inundated in a increased level of scintillation. Higher levels of scintillation generally correlate with higher levels of density and geomagnetic activity at Earth. In this case, the geomagnetic K-index at Earth increased to a level of 5 early 21 November, 1992.